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(4) EFFECT OF COLD REDUCTION AND THERMAL TREATMENT ON TENSILE PROPERTIES OF A NICKEL - 2 PERCENT BERYLLIUM ALLOY AT CRYOGENIC TEMPERATURES

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Start

SUMMARY

N.B.

This investigation was conducted to determine the tensile properties of a precipitation-hardenable nickel - 2 percent beryllium alloy (Berylco 440) in 0.020-inch-thick sheet form at temperatures from ambient to -423° F. The properties of this alloy over the range of commercially available conditions were determined, and the effects of extended aging times and temperatures as well as degrees of cold reduction greater than those commercially available were studied. Specimens parallel to the direction of rolling were tested at ambient temperature, -320° F, and -423° F. No transverse properties were determined. end

[Cryogenic testing]

The alloy studied has high toughness and elongation at cryogenic temperatures in comparison with other high-strength materials. When cold-reduced 60 percent and aged, yield and notch strengths at -423° F were 267 and 219 ksi, respectively, and average elongation was 19 percent. Overaging appeared to be of no benefit since it reduced the -423° F ultimate and yield strengths without increasing the notch strength. Comparison of the limited data obtained in this investigation and elevated-temperature data from the alloy supplier indicate that this alloy would be usable at temperatures ranging from -423° to about 800° F.

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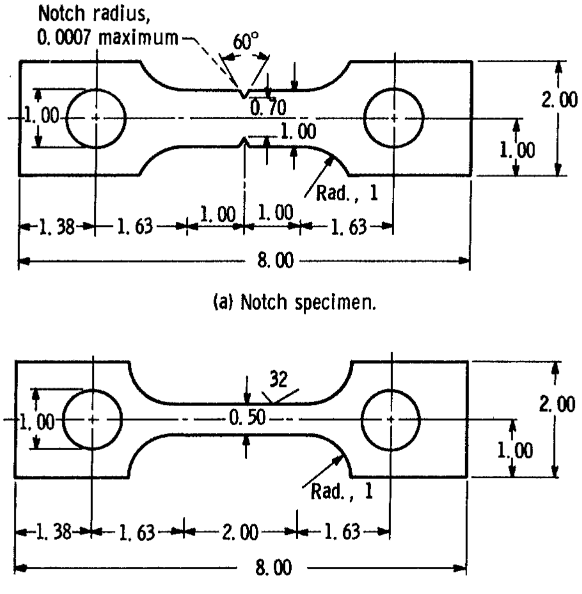
INTRODUCTION

Nickel and some of its alloys have several properties which make them attractive for use at cryogenic temperatures, such as moderate increases in strength with decreasing temperature, high toughness and ductility at cryogenic temperatures, and the lack of any abrupt change in properties with temperature change. The results of a program evaluating the strength and toughness at cryogenic temperatures of a nickel alloy containing approximately 2 percent beryllium are described herein.

Some nickel-base alloys, including Inconel X-750, have been evaluated (refs. 1 and 2) at cryogenic temperatures. However, Inconel X-750 and most



(a) Notch specimen.

(b) Smooth specimen.

Figure 1. - Smooth and sharp-edge-notch sheet tensile specimens. Material, 0.020 inch thick. (All dimensions in inches.)

others exhibit only moderate strength increases with thermal treatment and must be heavily cold-worked to attain high strength levels. Cold-worked materials are more difficult to form than annealed materials, and welds in cold-worked materials produce a local annealing effect that weakens the juncture.

Another nickel-base alloy (Berylco 440), which contains approximately 2 percent beryllium, has been investigated at the Lewis Research Center. According to reference 3, the room-temperature yield strength of this alloy in the solution-treated condition can be tripled by age-hardening alone; the hardening mechanism is a dispersion of fine beryllide particles. Further increases in strength can be obtained by cold-working after solution treatment and prior to aging. However, little data were available on the properties of this alloy at cryogenic temperatures.

In order to evaluate the possible merits of Berylco 440 alloy for cryogenic applications, a limited investigation was conducted. The longitudinal smooth and sharp-notch tensile properties of 0.020-inch-thick Berylco 440 sheet at ambient temperature, -320° and -423° F as well as the effects of cold reduction and subsequent aging are present in this report.

MATERIALS AND TEST SPECIMENS

Material (from two different heats) was received in the form of coupons 2 by 8 by 0.020 inches, which were solution-treated, cold-reduced, and aged by the supplier. The aging times and temperatures are listed in table I. The treatment designated "aged" is the normal aging treatment recommended by the supplier. For all coupons, the longest dimension was in the direction of rolling, that is, all specimens were longitudinal.

The coupons were then machined to the configurations shown in figure 1. For all notched specimens the notch root radius was not greater than 0.0007 inch (theoretical elastic stress concentration factor K_t, 21 or greater). In almost all cases at least three smooth and three notched specimens were tested at each test condition.

The nominal composition (percent by weight; ref. 3) of the alloy is beryllium, 1.95; titanium, 0.50; and nickel, the balance. The nominal density is 0.318 pound per cubic inch.

Three samples of material from the second heat were analyzed by the supplier; the results appear as table II. A discussion of the significance of the analysis would be premature at present; however, the information is included for future reference.

APPARATUS AND PROCEDURE

Specimens were tested in a universal testing machine. Strain was measured by using a clamp-on differential-transformer extensometer of 2-inch-gage length and an autographic stress-strain recorder. The extensometer was previously calibrated at all three test temperatures with a micrometer-driven calibration device.

Cryogenic test temperatures were established by immersing the specimen in liquid nitrogen or liquid hydrogen. A vacuum-jacketed cryostat was used to minimize boiloff. Correct cryogenic temperature was assured by maintaining the liquid level several inches above the upper specimen grip. Liquid-level sensing was accomplished by means of a carbon resistor.

Smooth tensile strength, yield strength (0.2 percent offset), sharp-notch tensile strength, and elongation (in 2 in.) were measured. The degrees of thermal treatment and cold reduction that were studied along with the temperatures at which properties were measured are also presented as part of table I.

Nominal fracture toughness calculation was based on equations given in reference 4 and the simplified approximate method of calculation given in reference 5 was used.

RESULTS AND DISCUSSION

Certain limitations must be considered in evaluating the data presented in this report. Since this alloy was tested in only one gage, the effect of thickness on its fracture toughness is not known. All tests were made parallel to the direction of rolling, thus transverse data are not available and the effects of anisotropy due to rolling were not determined. The material used to determine the effects of heavy cold reduction was from a heat different from that used to study overaging, and some differences are apparent. No attempt was made to ascertain the expected spread in data from a number of heats.

Tables III(a) and (b) list the average properties of nickel - 2 percent beryllium alloy from the first and second heats, respectively, for the material and test conditions investigated. In all cases but one, these data represent the averages of three or more specimens tested per condition. A measure of the experimental scatter is also represented in table III as the average and maximum deviations for ultimate, yield, and notch strengths. The average mean deviation is taken as the arithmetic average of the individual deviations (expressed in percent) from their corresponding mean values. The maximum mean deviation represents the largest deviation from a mean value that was observed. In table III(a), for example, the ultimate strength values averaged within

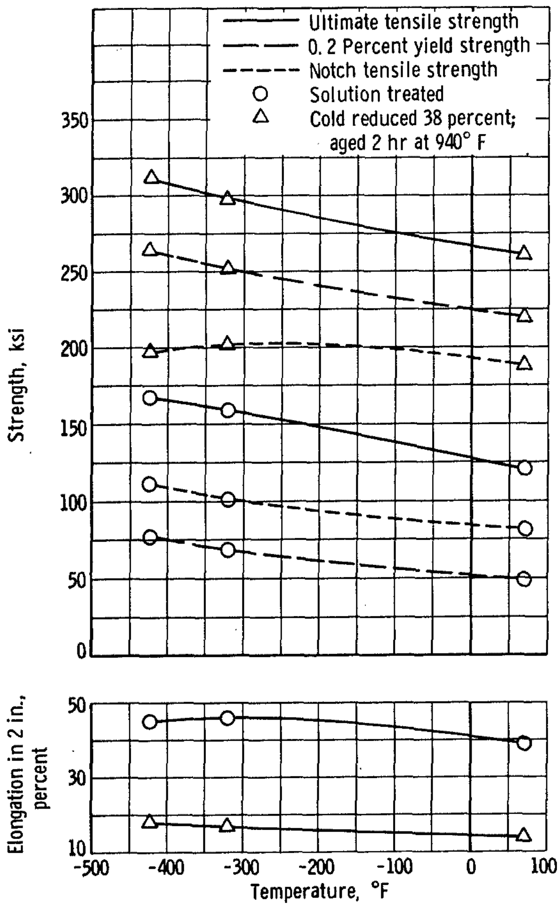


Figure 2. - Tensile properties of Berylco 440 alloy in extremes of commercially available conditions as functions of temperature.

±0.66 percent of their mean values and the worst point was within 3.09 percent. In table IV the individual values measured are given.

Tensile Properties of Alloy in Commercially Available Conditions

Berylco 440 alloy is normally available in cold reductions up to about 38 percent both with and without subsequent aging. The standard strengthening process consists of solution treatment at 1825° F, cold reduction if desired, and aging at about 940° F for about 2 hours if desired. To illustrate the range of properties available before this investigation was begun, second-heat data are extracted from table III(b). In figure 2 these data for material solution-treated (unaged) and material cold-reduced 38 percent and aged are shown as functions of temperature.

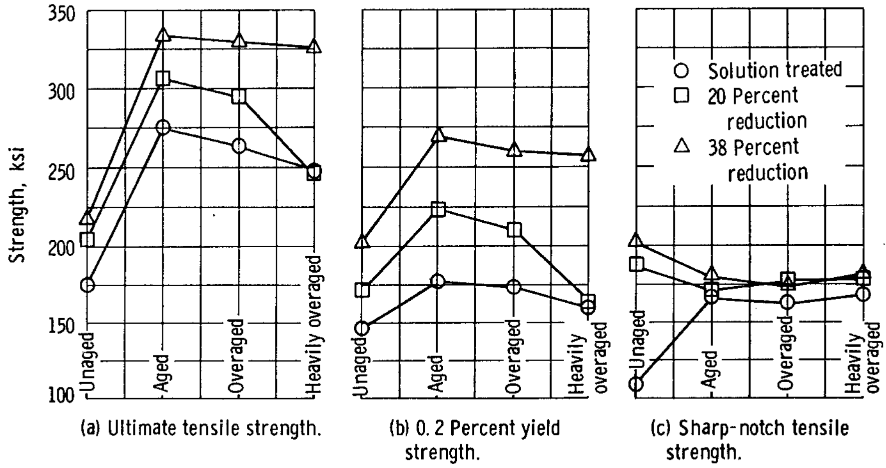
For the solution-treated condition, elongation is very high (about 40 percent) over the entire temperature range. Ultimate, yield, and notch strengths increase gradually with decreasing temperature, and the notch strength is considerably above the yield strength. The yield strength is rather low.

The material cold-reduced 38 percent and aged also exhibits a gradual increase in ultimate and yield strengths with decreasing temperature. The notch strength is somewhat below the yield strength but remains nearly constant at about 200 ksi. The elongation also remains nearly constant at about 16 percent over the temperature range studied.

These data indicate that within the range of commercially available material a wide range of properties can be obtained, depending on the degree of cold reduction and subsequent aging. The strongest conditions offer a fairly high yield strength; all conditions exhibit high elongation.

Influence of Aging on Properties at -423° F

Limited data obtained from the alloy supplier indicated that the cryogenic properties of the alloy might be improved further by increasing aging time



(a) Ultimate tensile strength. (b) 0.2 Percent yield strength. (c) Sharp-notch tensile strength.

Figure 3. - Effect of aging on properties of Berylco 440 alloy at -423° F.

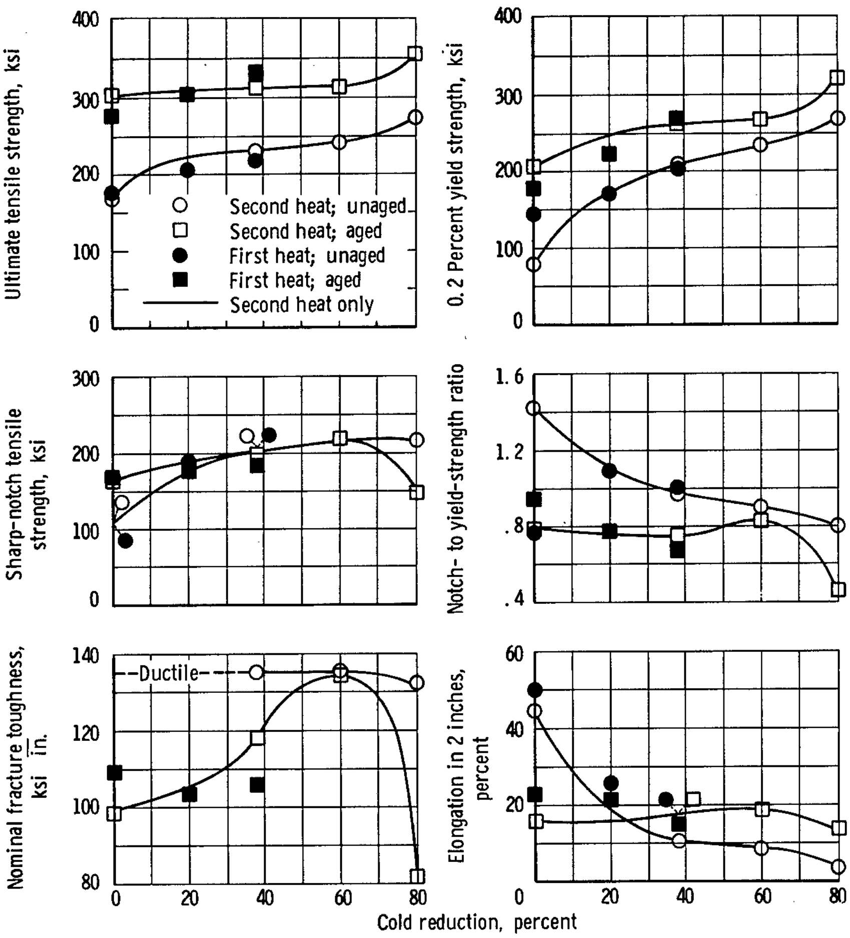


Figure 4. - Effect of cold reduction on properties of Berylco 440 alloy at -423° F.

and/or temperature, or "overaging." To determine the effects of overaging, material was obtained in three degrees of cold reduction (0, 20, and 38 percent reduction) and four degrees of aging (designated unaged, aged, overaged, and heavily overaged). The "aged" treatment is that recommended by the supplier; the specific thermal treatments are given in table I.

The results obtained in this phase of the investigation are listed in table III(a) and are shown graphically in figure 3. From figure 3 the normal aging cycle appears to be optimum, at least within the range studied. Further increases in aging time or temperature produce little if any increase in notch strength at -423° F and result in loss of tensile strength.

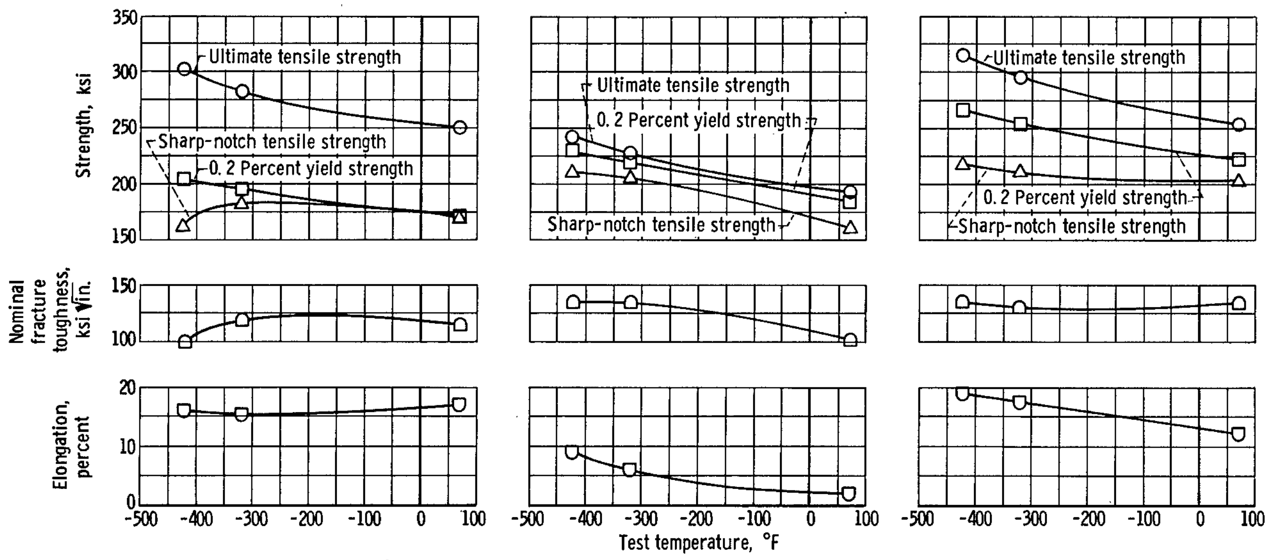
Influence of Cold Reduction on Properties at -423° F

Further investigation was made to determine the response of the nickel - 2 percent beryllium alloy to cold reduction in excess of that commercially available. Because of the results presented in the preceding section, the investigation of thermal treatment was limited to the normal aging treatment and the unaged conditon. Material (from a second heat) was obtained in four degrees of cold reduction (0, 38, 60, and 80 percent reduction) with and without the normal aging. The data obtained are presented as averages of at least three specimens per condition in table III(b). Figure 4 presents the effect of cold reduction on the tensile properties at -423° F for the unaged and the aged conditions. Applicable data (table III(a)), which was from a different heat of material, is also included (solid symbols) in figure 4, but the curves are drawn for the second heat (open symbols).

In figure 4 the ultimate and yield strengths are seen to increase with cold reduction. It should be noted that the yield strength of the aged material increases significantly with cold reduction above 60 percent. The notch strength also increases gradually with increasing cold reduction; but for the aged material, the notch strength falls off significantly with cold reductions above 60 percent. This fact, coupled with the previously noted increase of yield strength for this condition, would indicate that an embrittlement phenomenon is occurring which is associated with very high cold reductions followed by aging. This embrittlement does not seem apparent in the unaged material, and its cause has not been determined.

Resistance to brittle fracture as indicated by notch- to yield-strength ratio and nominal fracture toughness is also shown in figure 4. The solution-treated material is so ductile that the notch- to yield-strength ratio is considerably above unity and brittle fracture theories do not apply. The embrittlement phonomenon mentioned previously is evidenced here as a drastic drop in strength ratio and in toughness for the aged material above 60 percent reduction. The data also indicate that maximum toughness at -423° F is obtained at about 60 percent reduction and that at this reduction aging reduces the toughness only slightly.

When the two heats of material are compared (fig. 4), it is apparent that the same general trends occur for both heats. However, some significant dif-



(a) Solution-treated and aged $1\frac{1}{2}$ hours at 970° F.

(b) Cold-reduced 60 percent.

(c) Cold-reduced 60 percent, aged $1\frac{1}{2}$ hours at 940° F.

Figure 5. - Strength and elongation of Berylco 440 as functions of temperature.

ferences in mechanical properties exist between the two heats, particularly, the yield strength in the zero-reduction - no-age condition and the calculated values of fracture toughness. Based on the second heat of material (open symbols), the aged material at 60 percent reduction appears to give the best combination of mechanical properties, yielding high nominal fracture toughness at -423° F along with high ultimate and yield strengths. Although these data indicate the potential of the material, the variations in fracture toughness between the two heats would indicate that further material development is required before statistically reliable properties can be obtained.

Effect of Temperature on Properties at Selected Conditions

Figure 5 presents as functions of test temperature the tensile properties of Berylco 440 alloy in three conditions which are considered to be of greatest probable interest.

Figure 5(a) presents the tensile properties for the solution-treated-and-aged condition. This is probably the most interesting condition from the standpoint of fabrication. For example, a structure could be formed in the relatively soft solution-treated condition, then aged to increase its strength. Yield strength is about 175 ksi at room temperature and increases to about 200 ksi at -423° F. Notch strength, nominal fracture toughness, and elongation remain nearly constant from room temperature to -423° F, and elongation is very high - about 16 percent in 2 inches.

Figure 5(b) shows the tensile properties for the alloy when cold-reduced 60 percent with no subsequent aging. This condition represents (within the scope of this investigation) the maximum toughness at -423° F. Strength, tough-

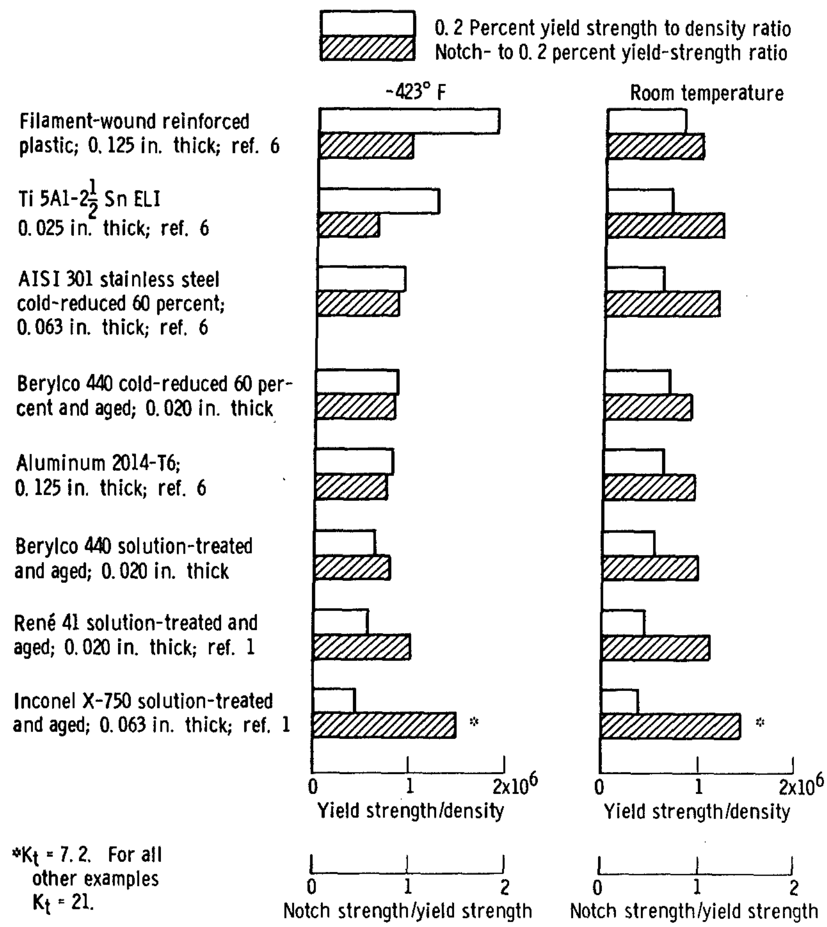


Figure 6. - Yield-strength to density and notch- to yield-strength ratios for several materials at -423° F and room temperature.

ness, and elongation all increase with decreasing temperature. Notch strength is only slightly below yield strength, and fracture toughness is quite high.

In figure 5(c) similar properties are given for Berylco 440 cold reduced 60 percent and aged. Following 60 percent cold reduction, aging increases the -423° F yield strength by about 30 ksi, increases the room-temperature fracture toughness by about 30 percent, and increases the -423° F ultimate elongation from 9 to 19 percent with only a very slight decrease in the fracture toughness at -423° F. In this condition (60 percent reduction followed by aging) Berylco 440 alloy has about 267-ksi yield strength, 219-ksi notch strength, and 19-percent elongation at -423° F.

Comparison with Other High-Strength Materials

In figure 6, Berylco 440 alloy is compared with several high-strength materials (data from refs. 1 and 6) on the basis of yield-strength to weight ratio and notch- to yield-strength ratio at -423° F and room temperature. Since the materials listed are not all the same thickness, not all the data are directly

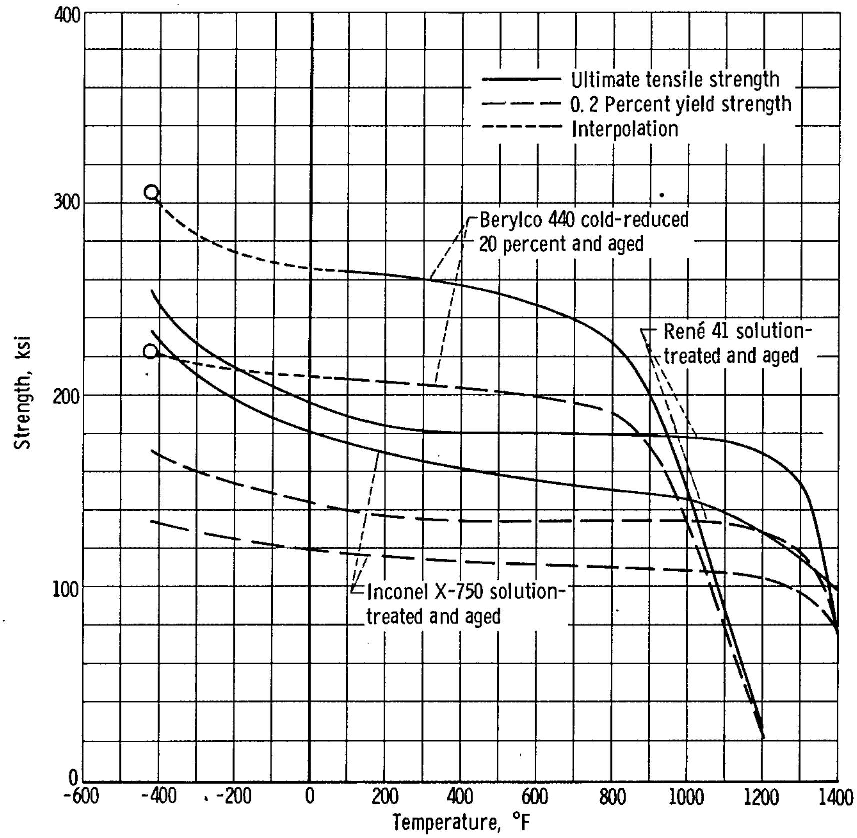


Figure 7. - Strength of Berylco 440 and two other nickel-base alloys as functions of temperature. Berylco 440: data below 70° F, this report; above 70° F, reference 3. René 41: data below 70° F, reference 1; above 70° F, reference 7. Inconel X-750: data below 70° F, reference 1; above 70° F, reference 8.

comparable. However, based on the data that are available, Berylco 440 could be competitive with other alloys that are currently used for cryogenic applications. For example, when cold-reduced 60 percent and aged, Berylco 440 has about the same strength to weight ratio at both temperatures as AISI 301 stainless steel cold-reduced 60 percent; when solution-treated and aged, Berylco 440 has a higher specific yield strength than René 41 or Inconel X-750 in the same condition.

Short-Time Elevated-Temperature Properties

Combining data from references 1, 3, 7, and 8 with data obtained in this investigation results in the curves shown in figure 7. Here the short-time ultimate and yield strengths for Berylco 440 (cold-reduced 20 percent and aged) are shown as functions of temperature from -423° to 1200° F and compared with similar properties for two other nickel-base alloys, René 41 and Inconel X-750. In this condition Berylco 440 is stronger than the other two alloys below about 900° F and its yield strength is nearly constant from -423° to about 800° F. Apparently this alloy may be useful in applications requiring high strength over a wide range of temperatures.

SUMMARY OF RESULTS

The results of this investigation of a nickel - 2 percent beryllium alloy, which was limited to the single thickness of 0.020 inch with properties determined only in the direction of rolling, indicate that this alloy, Berylco 440, has a combination of properties that may be useful for certain applications at cryogenic temperatures. Results may be summarized as follows:

1. In a sheet thickness of 0.020 inch and in the direction of rolling, this alloy has high strength, toughness, and elongation at cryogenic temperatures. For material solution-treated and aged, yield and notch strengths were 204 and 170 ksi, respectively, and average elongation was 16 percent at -423° F. For this alloy cold-reduced 60 percent and aged, -423° F yield and notch strengths were 267 and 219 ksi, respectively, and average elongation was 19 percent.

2. Based on available data for yield strength to weight ratio and notch-to yield-strength ratio at -423° F, it appears that Berylco 440 alloy could be competitive with other materials currently used for cryogenic applications.

3. The solution-treated and aged condition and the 60 percent cold-reduced condition (with and without aging) appear the most useful for cryogenic service.

4. Overaging would appear to be of no benefit since it reduces the -423° F ultimate and yield strengths without increasing the notch strength.

5. Data obtained in this investigation and elevated-temperature data from the alloy supplier indicate that this alloy would be usable at temperatures ranging from -423° to about 800° F.

6. Significant property differences observed between two heats of material indicate that further material development would be required before statistically reliable properties could be obtained.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 29, 1965.

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TABLE I. - DEGREES OF COLD REDUCTION AND THERMAL TREATMENT INVESTIGATED AND TEST TEMPERATURES AT WHICH TENSILE PROPERTIES WERE DETERMINED

[All specimens solution-treated before rolling.]

Cold reduction,[a] percent	Thermal treatment										
	Unaged	Aged			Overaged			Heavily overaged			
	Test temperature, °F	Aging	cycle	Test temperature, °F	Aging	cycle	Test temperature, °F	Aging	cycle	Test temperature, °F
0	70 -320 -423	1 1/2	970	70 -320 -423	3 1/2	970	-423	2	1020	-423
20	-423	2	940	-423	3/4	1000	-423	2	1000	-423
38	70 -320 -423	2	940	70 -320 -423	1 1/2	1000	-423	2 1/2	1000	-423
60	70 -320 -423	1 1/2	940	70 -320 -423	Not tested			Not tested		
80	70 -320 -423	1 1/2	940	70 -320 -423	Not tested			Not tested		

[a]Following solution treatment and preceeding aging.

TABLE II. - ANALYSIS (BY SUPPLIER) OF THREE

UNAGED SAMPLES FROM SECOND HEAT

Constituent, percent by weight	Sample		
	A	B	C
	Reduction, percent		
	38	60	80
Beryllium	1.97	1.97	1.86
Titanium	.42	.44	.43
Iron	.054	.017	.11
Silicon	.11	.13	.11
Aluminum	.043	.010	.092
Chromium	.010	.01	.01
Magnesium	.011	.010	.012
Nickel	Bal.	Bal.	Bal.

TABLE III. - AVERAGE TENSILE PROPERTIES OF BERYLCO 440 ALLOY

[Thickness, 0.020 in.]

(a) From first heat

Cold reduction, percent	Thermal treatment, hr	Thermal treatment, ^{o}F	Rockwell hardness (70^{o} F)	Test temperature, ^{o}F	Ultimate tensile strength, ksi	0.2 percent yield strength, ksi	Sharp-notch tensile strength, ksi	Notch- to yield-strength ratio	Nominal fracture toughness, ksi $\sqrt{in.}$	Elastic modulus, psi	Elongation percent in 2 in.
0	--	----	B83	-423	174.5	145.8	110.6	0.759	66.6	30.3×10^{6}	50
	$1\frac{1}{2}$	970	C48		275.4	176.9	166.9	.943	109.5	31.7	23
	$3\frac{1}{2}$	970	C43		263.8	173.9	163.0	.937	106.6	31.3	$15\frac{1}{2}$
	2	1020	C35		248.8	160.2	168.1	1.049	(a)	31.5	$15\frac{1}{2}$
20	--	----	C34	-423	205.6	171.5	187.3	1.092	(a)	32.6×10^{6}	$26\frac{1}{2}$
	2	940	C51		306.5	223.3	171.7	.769	103.7	33.0	$21\frac{1}{2}$
	$\frac{3}{4}$	1000	C48		294.9	210.3	178.6	.849	111.4	32.5	22
	2	1000	C39		246.5	163.2	179.4	1.099	(a)	33.2	26
38	--	----	C39	-423	218.2	202.5	202.6	1.000	(a)	30.7×10^{6}	18
	2	940	C53		334.0	268.7	180.8	.673	105.9	34.5	16
	$1\frac{1}{2}$	1000	C51		330.0	260.3	175.4	.674	102.9	33.8	$16\frac{1}{2}$
	$2\frac{1}{2}$	1000	C41		327.4	257.8	181.3	.703	107.1	32.3	17
Average mean deviation, percent					0.66	1.75	4.51	-----	-----	----	---
Maximum mean deviation, percent					3.09	11.59	13.68	-----	-----	----	---

(b) From second heat

Cold reduction, percent	Thermal treatment, hr	Thermal treatment, ^{o}F	Rockwell hardness (70^{o} F)	Test temperature, ^{o}F	Ultimate tensile strength, ksi	0.2 percent yield strength, ksi	Sharp-notch tensile strength, ksi	Notch- to yield-strength ratio	Nominal fracture toughness, ksi $\sqrt{in.}$	Elastic modulus, psi	Elongation percent in 2 in.
0	--	----	B69	70	119.5	48.0	80.8	1.683	(a)	28.8×10^{6}	39
				-320	159.0	68.7	102.1	1.486	(a)	31.8	46
				-423	167.3	77.6	111.1	1.432	(a)	31.6	45
	$1\frac{1}{2}$	970	C48	70	251.3	172.1	170.8	0.992	115.6	30.0×10^{6}	17
				-320	282.7	195.9	182.6	.932	119.0	31.8	$15\frac{1}{2}$
				-423	303.0	204.2	162.5	.796	99.2	32.8	16
38	--	----	C37	70	182.9	174.5	157.5	0.903	101.3	27.5×10^{6}	$2\frac{1}{2}$
				-320	215.0	198.1	189.7	.958	125.6	33.2	11
				-423	232.2	210.5	203.7	.968	135.8	31.4	$10\frac{1}{2}$
	2	940	C49	70	260.2	218.6	187.7	0.859	117.7	30.6×10^{6}	15
				-320	297.6	252.0	201.9	.801	123.5	33.7	17
				-423	311.7	263.5	197.0	.748	118.2	33.9	18
60	--	----	C40	70	191.3	184.6	161.1	0.873	101.7	27.3×10^{6}	2
				-320	228.8	219.3	206.6	.942	135.4	30.9	6
				-423	242.0	234.1	211.3	.903	135.8	30.9	9
	$1\frac{1}{2}$	940	C48	70	253.7	222.5	203.3	0.914	131.1	30.1×10^{6}	12
				-320	296.3	254.4	210.8	.829	130.4	32.3	$17\frac{1}{2}$
				-423	314.9	266.7	218.7	.820	134.8	32.9	19
80	--	----	C44	70	215.9	211.3	177.5	0.840	110.3	26.3×10^{6}	$1\frac{1}{2}$
				-320	256.0	249.7	226.4	.907	145.5	29.3	$3\frac{1}{2}$
				-423	274.9	268.2	215.7	.804	132.1	29.9	4
	$1\frac{1}{2}$	940	C55	70	289.6	264.7	155.7	0.588	89.3	29.1×10^{6}	7
				-320	337.8	304.5	158.4	.520	89.5	32.2	$12\frac{1}{2}$
				-423	357.9	319.8	146.6	.458	81.8	31.2	14
Average mean deviation, percent					0.71	1.12	2.86	-----	-----	----	---
Maximum mean deviation, percent					2.61	6.59	12.09	-----	-----	----	---

[a]Ductile fracture; fracture toughness criterion does not apply.

TABLE IV. - EXPERIMENTAL DATA FOR TWO HEATS OF MATERIAL

(a) First heat. Test temperature, -423° F

Cold reduction, percent	Aging cycle, hr	Aging cycle, °F	Ultimate tensile strength, ksi	0.2 percent yield strength, ksi	Elastic modulus, psi	Elongation, percent	Notch strength, ksi
0	--	----	175.5	162.7	29.8×10^{6}	50	110.4
			(a)	(a)	30.9	(a)	111.4
			173.4	128.9	30.2	(b)	109.9
			[c]174.5	[c]145.8	[c]30.3	[c] 50	[c]110.6
	$1\frac{1}{2}$	970	281.6	181.1	32.6×10^{6}	23	178.8
			277.6	171.8	29.6	(d)	170.2
			266.9	177.9	32.8	(b)	151.6
			[c]275.4	[c]176.9	[c]31.7	[c] 23	[c]166.9
	$3\frac{1}{2}$	970	265.5	167.8	30.6×10^{6}	16	171.7
			258.9	173.7	29.8	15	155.7
			267.0	180.3	33.5	(b)	161.7
			[c]263.8	[c]173.9	[c]31.3	[c] $15\frac{1}{2}$	[c]163.0
	2	1020	250.5	163.7	32.0×10^{6}	18	158.8
			248.5	159.4	31.4	13	179.9
			247.5	157.4	31.2	(b)	165.7
			[c]248.8	[c]160.2	[c]31.5	[c] $15\frac{1}{2}$	[c]168.1
20	--	----	205.3	173.4	31.4×10^{6}	26	187.4
			205.3	170.2	34.4	27	179.7
			206.1	170.9	31.9	(b)	194.8
			[c]205.6	[c]171.5	[c]32.6	[c] $26\frac{1}{2}$	[c]187.3
	2	940	301.5	218.4	31.4×10^{6}	21	193.0
			308.5	225.3	32.9	22	154.3
			309.6	226.1	34.8	(b)	167.8
			[c]306.5	[c]223.3	[c]33.0	[c] $21\frac{1}{2}$	[c]171.7
	$\frac{3}{4}$	1000	291.6	205.5	31.4×10^{6}	22	180.9
			295.1	215.1	32.8	22	189.4
			298.0	210.3	33.4	(b)	165.6
			[c]294.9	[c]210.3	[c]32.5	[c] 22	[c]178.6
	2	1000	248.3	164.6	31.2×10^{6}	27	178.3
			246.1	163.4	32.2	25	185.1
			245.3	161.6	36.1	(b)	174.7
			[c]246.5	[c]163.2	[c]33.2	[c] 26	[c]179.4
38	--	----	217.3	201.0	30.4×10^{6}	18	218.1
			218.4	201.8	29.8	18	185.3
			218.9	204.7	32.0	(b)	204.3
			[c]218.2	[c]202.5	[c]30.7	[c] 18	[c]202.6
	2	940	333.8	268.5	34.6×10^{6}	16	179.6
			334.3	266.9	34.2	(d)	181.3
			333.8	270.6	34.6	(b)	181.6
			[c]334.0	[c]268.7	[c]34.5	[c] 16	[c]180.8
	$1\frac{1}{2}$	1000	331.5	260.1	33.8×10^{6}	17	191.9
			328.1	262.1	32.8	16	171.2
			330.5	258.8	34.9	(b)	163.2
			[c]330.0	[c]260.3	[c]33.8	[c] $16\frac{1}{2}$	[c]175.4
	$2\frac{1}{2}$	1000	328.9	258.9	33.0×10^{6}	(d)	182.2
			326.6	254.6	32.8	17	205.1
			326.8	259.8	31.2	(b)	156.5
			[c]327.4	[c]257.8	[c]32.3	[c] 17	[c]181.3

[a]Specimen failed in head because of machining flaw.
[b]Not measured.
[c]Average value.
[d]Could not be measured.

TABLE IV. - Continued. EXPERIMENTAL DATA FOR TWO HEATS OF MATERIAL

(b) Second heat

Cold reduction, percent	Aging cycle, hr	Aging cycle, °F	Test temperature, °F	Ultimate tensile strength, ksi	0.2 percent yield strength, ksi	Elastic modulus, psi	Elongation, percent	Notch strength, ksi
0	--	----	70	119.8	48.0	28.8×10^6	39	81.8
				119.4	48.0	28.0	39	80.8
				119.2	48.1	29.6	38	80.5
				[c]119.5	[c]48.0	[c]28.8	[c]39	[c]80.8
			-320	161.5	67.8	29.8×10^6	$47\frac{1}{2}$	102.3
				158.5	69.1	33.0	45	101.5
				156.9	69.1	32.6	46	102.3
				[c]159.0	[c]68.7	[c]31.8	[c]46	[c]102.1
			-423	[e]155.0	76.6	31.7×10^6	$37\frac{1}{2}$	112.0
				166.8	80.3	32.1	42	111.7
				169.4	78.5	32.9	56	110.8
				165.7	75.0	29.8	$44\frac{1}{2}$	109.9
				[c]167.3	[c]77.6	[c]31.6	[c]45	[c]111.1
	$1\frac{1}{2}$	970	70	253.6	171.5	29.3×10^6	18	168.4
				250.7	172.8	30.8	17	175.2
				249.5	172.1	29.8	$17\frac{1}{2}$	168.9
				[c]251.3	[c]172.1	[c]30.0	[c]$17\frac{1}{2}$	[c]170.8
			-320	[e]261.9	193.8	31.6×10^6	19	190.0
				278.6	195.7	31.8	13	172.2
				283.9	196.9	31.9	15	185.5
				285.6	197.1	31.7	15	-----
				[c]282.7	[c]195.9	[c]31.8	[c]$15\frac{1}{2}$	[c]182.6
			-423	297.1	203.8	31.2×10^6	$14\frac{1}{2}$	168.5
				305.3	206.1	33.3	15	[e]191.7
				306.4	202.7	33.8	18	155.7
				-----	-----	----	--	163.4
				[c]303.0	[c]204.2	[c]32.8	[c]16	[c]162.5
38	--	----	70	182.3	172.0	[e]23.8×10^6	$2\frac{1}{2}$	161.8
				182.3	175.5	27.9	$2\frac{1}{2}$	156.9
				184.0	176.1	27.2	3	153.9
				[c]182.9	[c]174.5	[c]27.5	[c]$2\frac{1}{2}$	[c]157.5
			-320	216.6	200.1	33.6×10^6	11	192.6
				216.2	202.5	33.1	10	178.3
				212.2	191.7	32.9	$11\frac{1}{2}$	198.3
				[c]215.0	[c]198.1	[c]33.2	[c]11	[c]189.7
			-423	234.4	199.8	31.5×10^6	8	199.4
				232.5	216.7	32.0	12	194.0
				229.6	215.0	29.4	11	217.8
				[e]242.9	224.1	32.7	11	[e]184.8
				[c]232.2	[c]213.9	[c]31.4	[c]$10\frac{1}{2}$	[c]203.7
	2	940	70	256.2	217.0	30.8×10^6	15	182.8
				262.1	220.1	30.3	$15\frac{1}{2}$	184.4
				262.4	218.7	30.8	15	195.9
				[c]260.2	[c]218.6	[c]30.6	[c]15	[c]187.7
			-320	297.5	248.4	32.7×10^6	18	190.7
				[e]274.8	[e]219.6	34.2	19	188.6
				299.2	248.5	32.4	19	226.3
				296.2	259.2	35.4	13	-----
				[c]297.6	[c]252.0	[c]33.7	[c]17	[c]201.9
			-423	310.0	259.8	33.0×10^6	$19\frac{1}{2}$	209.2
				311.2	264.2	34.8	18	203.2
				313.8	266.6	33.8	17	186.7
				-----	-----	----	--	189.0
				[c]311.7	[c]263.8	[c]33.9	[c]18	[c]197.0

TABLE IV. - Concluded. EXPERIMENTAL DATA FOR TWO HEATS OF MATERIAL

(b) Concluded. Second heat

Cold reduction, percent	Aging cycle		Test temperature, °F	Ultimate tensile strength, ksi	0.2 percent yield strength, ksi	Elastic modulus, psi	Elongation, percent	Notch strength, ksi
	hr	°F						
60	--	----	70	193.9	187.4	28.2×10^6	2	154.3
				186.3	178.6	26.2	$1\frac{1}{2}$	164.6
				193.8	187.8	27.5	2	165.8
				-----	-----	----	-	159.7
				[c]191.3	[c]184.6	[c]27.3	[c]2	[c]161.1
			-320	227.5	217.9	31.6×10^6	6	209.6
				230.8	222.2	30.5	6	206.2
				228.0	217.7	30.6	5	203.9
				[c]228.8	[c]219.3	[c]30.9	[c]6	[c]206.6
			-423	242.6	234.5	30.4×10^6	9	200.7
				240.9	(d)	29.9	9	212.2
				242.6	231.9	33.0	8	220.9
				[e]257.1	235.8	30.2	$10\frac{1}{2}$	-----
				[c]242.0	[c]234.1	[c]30.9	[c]9	[c]211.3
	$1\frac{1}{2}$	940	70	254.3	222.5	30.0×10^6	$12\frac{1}{2}$	201.3
				254.4	223.3	30.8	12	198.9
				252.5	221.8	29.6	13	209.7
				[c]253.7	[c]222.5	[c]30.1	[c]12	[c]203.3
			-320	297.5	254.0	31.9×10^6	$17\frac{1}{2}$	214.4
				288.9	256.1	32.2	19	207.8
				299.9	254.8	32.4	16	195.9
				298.7	252.8	32.8	18	224.9
				[c]296.3	[c]254.4	[c]32.3	[c]$17\frac{1}{2}$	[c]210.8
			-423	312.7	266.9	32.7×10^6	$19\frac{1}{2}$	217.6
				315.2	265.4	33.2	19	213.5
				316.7	267.7	32.9	$18\frac{1}{2}$	225.0
				[c]314.9	[c]266.7	[c]32.9	[c]19	[c]218.7
80	--	----	70	215.3	210.9	27.0×10^6	$1\frac{1}{2}$	181.1
				213.6	209.2	26.0	$1\frac{1}{2}$	169.7
				218.7	213.7	25.9	1	181.7
				[c]215.9	[c]211.3	[c]26.3	[c]$1\frac{1}{2}$	[c]177.5
			-320	253.7	247.3	29.7×10^6	$2\frac{1}{2}$	225.0
				257.7	250.7	29.4	$3\frac{1}{2}$	225.3
				256.7	251.2	28.8	4	228.8
				[c]256.0	[c]249.7	[c]29.3	[c]$3\frac{1}{2}$	[c]226.4
			-423	274.5	270.6	29.9×10^6	4	235.2
				273.1	266.1	28.5	4	214.0
				273.4	267.5	31.6	4	198.2
				278.6	268.7	29.4	3	215.2
				[c]274.9	[c]268.2	[c]29.9	[c]4	[c]215.7
	$1\frac{1}{2}$	940	70	288.2	262.2	28.1×10^6	7	159.8
				289.2	265.0	29.3	7	159.0
				291.5	266.8	30.0	7	148.3
				[c]289.6	[c]264.7	[c]29.1	[c]7	[c]155.7
			-320	334.8	293.3	31.6×10^6	11	161.2
				341.5	314.0	32.2	13	155.5
				337.8	316.5	34.2	12	158.5
				337.2	294.1	30.9	14	-----
				[c]337.8	[c]304.5	[c]32.2	[c]$12\frac{1}{2}$	[c]158.4
			-423	359.0	318.7	31.6×10^6	14	135.6
				356.2	318.0	30.7	14	154.1
				358.5	322.7	33.5	(d)	150.0
				[c]357.9	[c]319.8	[c]31.2	[c]14	[c]146.6

[e]Data rejected from computation because of extreme deviation from mean.